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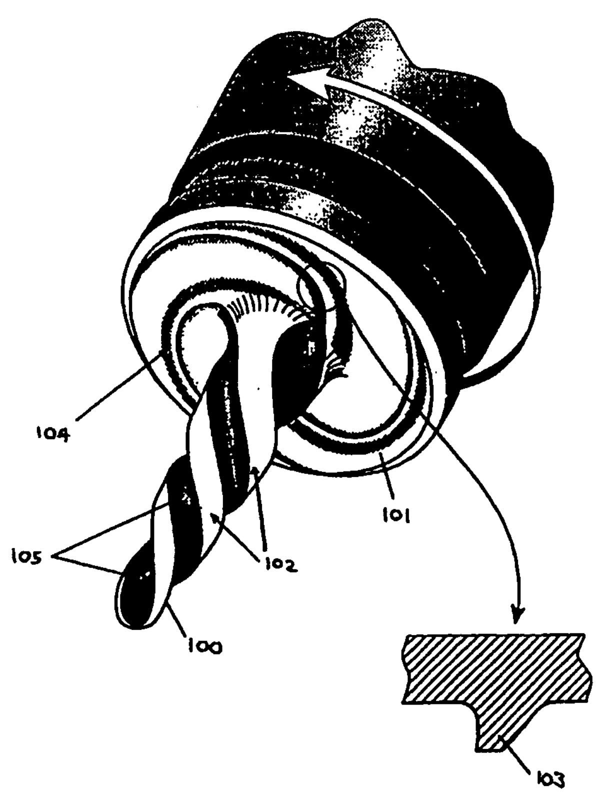
(57) Abstract

A friction stir welding tool comprises a body defining a shoulder (101) from which a probe (100) extends. The probe (100) has at least three flutes (105) along its length.



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HIGH PERFORMANCE TOOLS FOR FRICTION STIR WELDING (FSW)

This invention relates to Friction Stir Welding (FSW) and, in particular, to tools for deep penetration in a variety of materials in simple butt joint configuration and the like. Such tools, hereinafter referred to as of the kind described, comprise a body defining a shoulder from which a probe extends.

Friction stir welding is a method in which a probe of material harder than the workpiece material is caused to enter the joint region and opposed portions of the workpieces on either side of the joint region while causing relative cyclic movement (for example rotational or reciprocal) between the probe and the workpieces whereby frictional heat is generated to cause the opposed portions to take up a plasticised condition; optionally causing relative movement between the workpieces and the probe in the direction of the joint region; removing the probe; and allowing the plasticised portions to consolidate and join the workpieces together. Examples of friction stir welding are described in EP-B-0615480 and WO 95/26254.

Conventionally, the tool used for FSW comprises a simple cylindrical or slightly tapered probe projecting from a larger diameter flat or slightly domed shoulder, as shown in Figure 1. It is noted that the depth to width ratio of the probe length versus its nominal diameter is of the order of 1:1 or even less, and that the ratio of the shoulder diameter to the probe length is of the order of 3:1 or even 4:1, as first disclosed in EP-B-0615480 for welding 3mm thick and 6mm thick sheets and plates in an aluminium alloy.

A variety of tools are described in GB-A-2306366.

For welding thicker plate, of say 15mm thickness and greater such as 25mm, in a single pass, although probes of 1:1 length/diameter ratio could be used, this is inefficient in that such probes displace an excessive amount of material.

In accordance with one aspect of the present invention, a friction stir welding tool comprises a body defining a shoulder from which a probe extends, the probe having at least three flutes along its length.

A fluted probe has been found to produce very strong welds and to have a better performance than the tools previously known. The flutes constitute grooves which may extend either linearly or in a helical manner along the probe axis.

Furthermore, we have found that including a buttress thread on the fluted probe considerably increases the efficiency of the weld produced by the tool allowing much thicker workpieces to be welded. We believe the buttress thread causes material to be worked prior to the action of the flutes.

Preferably, the probe has an odd number of flutes, for example three, five or seven, most particularly three. However, an even number of flutes could also be used.

In another aspect of the invention, a tool of the kind described includes a relatively slender probe of some 2:1, or even 3:1 or more, length/diameter ratio. The probe diameter is measured at its root.

In accordance with a third aspect of the present invention, a tool of the kind described has a shoulder with a diameter such that the ratio of shoulder diameter to probe length is 2:1, 1:1 or less.

In accordance with a fourth aspect of the present invention, a tool of the kind described includes a shoulder having one or more annular ribs extending around the root of the probe, at least one of the ribs having at least one further raised portion or alternatively having scrolls on the shoulder instead of annular ribs.

Each of these aspects of the invention may be used alone or in combination with one or more of the others. A particularly preferred combination involves all four aspects of the invention.

It is a particular advantage with such slender probes with relatively reduced shoulder areas, to enhance the working of the plasticised material to beneficial effect. This is advantageous since the frictional heat previously available from the contact of the shoulder with the work is relatively lessened both due to the reduced ratio of shoulder diameter to probe length, and due to the increased path length for such surface heating to travel to reach the extremity of the probe. It should also be noted that the change in section between the shoulder and the probe is well radiused in order to reduce stress concentration.

In a preferred aspect, the retaining of plasticised material from escape from under such relatively reduced shoulders is enhanced by additional dams, or inwardly facing ribs, mounted on the shoulder face. In addition, means may be provided for a degree of downward thrust to the plasticised material in the vicinity of the probe by suitable orientation of ridges or blades on the "lands" (the extreme outer surfaces between the flutes) of the probe. A further advantage is to reduce the obstruction presented by the probe to the flow of plasticised material past the probe as it moves along the joint path, such that the instantaneous section presented by the probe is less than its swept section of rotation.

These and other features are disclosed and exemplified in the following illustrations, in which:-

Figure 1a shows a known single ended friction stir welding probe and shoulder;

Figure 1b shows a side view of a known single ended friction stir welding probe and shoulder;

Figure 1c shows a known bobbin type friction stir welding probe and shoulder;

Figure 2 shows a basic overall geometry for an enhanced probe of greater length to diameter ratio together with an inward spiral scroll on the shoulder;

Figure 3a shows an alternative arrangement with a spiral scroll on the shoulder and an additional buttress type single helix ridge on the outer portion of the tool;

Figure 3b shows an arrangement with a buttress type single helix ridge and concentric shoulder rings with raised portions;

Figure 3c shows an arrangement in which the flutes have a smaller pitch;

Figure 4 shows a typical macrosection of a relatively deep weld in a single pass in an aluminium alloy using the method of Figure 2; and,

Figure 5 illustrates diagrammatically the flow of plasticised material passing a non-circular probe.

In the example of common practice shown in Figure 1a, a pair of aluminium plates 1A,1B are butted together about a joint line 2, together with a non-consumable nominally cylindrical probe 3 of material harder than the workpieces which is pressed into the plates 1A,1B in the vicinity of the joint line but which does not extend completely through the thickness of the materials being joined. The tool material may be for example tool steel for the joining of light alloys; pure tungsten, tungsten rhenium alloy or tungsten carbide for ferrous materials; or any other sufficiently hard and tough material for the application concerned, for example cobalt materials, ceramic or cermet materials. The nominally cylindrical probe 3 and its shoulder 10 are more clearly shown diagrammatically in elevation in Figure 1b. Preferably, the probe has a blunt, nominally spherical, nose 18 to assist penetration until the depth of penetration is arrested by contact between the shoulder 10 and the upper surface of the workpieces 1A,1B. Although the outer edge 10A of the shoulder is slightly chamfered as shown, it is noted that the width of the contact zone 9, which appears as a series of semi-circular ripples on the upper surface of the work, is of the order of at least three, if not four times the thickness of the workpieces. Also, the nominal maximum diameter of the

slightly tapered cylindrical probe is of the same order as the thickness of the workpieces.

A double ended probe or bobbin with a shoulder bearing on both upper and lower surfaces of the workpieces is shown in Figure 1c, where for thin sheet the length to diameter ratio of the probe is even less than 1:1 ratio and approaches 0.5:1 ratio.

Such probes are disclosed in EP-B-0615480.

Figure 2 illustrates a basic example of the modified probe for deep section butt welding. In essence, the probe 100 is tapered so as to maintain approximately uniform stress due to both torsion and forward thrust along its length owing to travel along the joint line, or at least a stress at its end adjacent the shoulder 101, which stress is not greater than two or three times the stress towards the remote end due to torsion and thrust. This modified probe is deeply grooved so as to enhance the working of the plasticised material so formed from frictional heat due to rotation of the probe in the workpiece. In the example shown, the surface of the probe is scalloped to give a deep spiral like projection which executes approximately one complete turn in the length of the probe and in which three ridges 102 are provided as in a multi-start arrangement to define three grooves or flutes 105. This is to be distinguished from a screw thread in which the ridges of the thread are substantially normal to the axis of rotation, whereas in this case the helix angle that the ridge 102 makes with the axis of the probe is of the order of 45° or less. In one extreme, the ridges 102 can run parallel with the axis of rotation (angle nominally zero). In this case, there is nominally no downward action along the probe axis and the working of the plasticised material is substantially circumferential. Alternatively, with a steeply angled ridge, as illustrated, there is not only a circumferential stirring but also a significant degree of auguring effect, which tends to oppose the escape of plasticised material towards the shoulder.

In the example, flutes 105 commence at equally spaced circumferential intervals around the probe and have substantially the same pitch.

In this example, the shoulder 101 is provided with a spiral ridges 103 which act in an inward direction with the given rotation, again to reduce the tendency of plasticised material to escape, especially on the surface of the workpiece. The spiral ridge may again be in a form of a multi-start spiral with three starts as illustrated in Figure 2 forming an archimedial three spiral scroll 104. However, other shoulder profiles could also be used such as one or two concentric ridges.

Figure 3a illustrates an example of a tool 150 having a shoulder 151 provided with a spiral ridge 152 similar to the ridge 103 in Figure 2. The probe 153 extending from the shoulder 151 is deeply spiralled and includes three flutes 155. In addition, the outer surface of the probe 153 is provided with a well radiused buttress type thread 154. The buttress thread is defined by a relatively flat face 156 which faces substantially along the length of the probe 153 and a sloping face 157 on its other side. Although not shown, a similar buttress thread could be incorporated in the Figure 2 tool.

Figure 3b illustrates a similar deeply spiralled probe, as in Figure 2, but with a shoulder 110 provided with concentric rings 111 to impede the escape of plasticised material under the shoulder. These rings are continuous or alternatively have further raised portions 112 to allow plasticised material from the surface to be worked as the probe is traversed along the joint line. As in Figure 3a, a buttress thread 113 is provided on the outer diameter lands of the probe.

Figure 3c shows a probe similar to that of Figure 3b. In this case four flutes 170 are provided which have a smaller pitch (i.e. a larger helix angle) in comparison with those of Figure 3b.

Figure 4 shows a typical macrosection in aluminium alloy of a friction stir weld made with a probe of the Figure 2 type configuration with a relatively large length to probe diameter ratio (e.g. 20mm diameter and nominally 50mm long in the case of joining aluminium alloys). It is noted that the heat affected zone (HAZ) arising from the shoulder contact with the upper surface of the workpiece does not extend through the thickness of the plate as is commonly found in friction stir welding with thin plate of the order of 6mm thickness. The spiral ridge 103 on the shoulder of the tool also helps to develop frictional heat as well as causing an inward movement of the surface plasticised material, which would otherwise tend to escape and, with a nominally flat surface to the shoulder, lead to reduced heat input.

The probe tool can operate on each side in turn or two probes can be operated substantially simultaneously. Looking from the end of the workpiece this will be opposed rotation to provide balanced torque.

The detailed profile of the ridge on the shoulder and on the nominally tapered cylindrical probe is preferably arranged with a relatively greater space between the ridges than the thickness of the ridge itself. This is unlike a screw thread where nominally at mid height the width of the thread is equal to the width of the spacing between threads. Furthermore, the downward surface of the ridge can be substantially normal to the probe axis or be inwardly curved to entrap plasticised material the more readily. Correspondingly the reverse side of the ridge can be sloped or profiled again to aid downward motion of the plasticised material. Preferably the outer ridge is helical but can be a series of slightly inclined ridges to provide a similar effect.

Similarly, Figures 2 and 3a show details of the section of the ridge on the tool shoulder where again the inward acting face is substantially normal to the plane of the shoulder and the reverse face is sloped so as to

encourage motion of the plasticised material in the desired direction.

The same considerations apply to a shoulder with concentric ridges with the further provision that the concentric ring need not be of uniform depth but can have further raised portions.

Figure 5 illustrates diagrammatically the pressure and flow developed in the plasticised material as viewed along the axis of the probe. A Triflute™ probe 200 is exemplified in four positions over time denoted by the time axis 250, the relative substrate motion being denoted by axis 251. High and low pressure positions are denoted by numerals 205 and 206 respectively. During rotation it is apparent that a path 210 is developed to allow plasticised material to flow past the probe 200 within the zone swept by the extremities or peaks of the probe section. Minor flow paths are also indicated by numerals 211 and 212. As noted above, the flutes or ridges on the probe may be substantially parallel to the probe axis or orientated at a significant angle to develop a degree of longitudinal stirring of the plasticised material along the probe length.

The included angle of the tapered probe can vary between 5° and 23° (with 16°-20° included angle being preferred). The smaller the included angle the greater the stress at the root and angles less than 5° can result in failures at the root. Included angles greater than 23° can result in the tip of the probe twisting off by torsional shearing. The angle of the flutes can vary between 1° off axis (almost parallel with the probe axis) to about 60° off axis, whilst the buttress type helix will be similar to that of a coarse thread.

CLAIMS

1. A friction stir welding tool comprising a body defining a shoulder from which a probe extends, the probe having at least three flutes along its length.

2. A tool according to claim 1, wherein a buttress thread is superimposed on the probe.

3. A tool according to claim 1 or claim 2, wherein the probe tapers inwardly in a direction away from the shoulder.

4. A tool according to any of the preceding claims, wherein the probe has a length/diameter ratio of at least 2:1.

5. A tool according to any of the preceding claims, wherein the shoulder has a profile defined by one or two concentric ridges.

6. A tool according to claim 5, wherein at least one of the ribs has at least one further raised portion.

7. A tool according to any of the preceding claims, wherein the ratio of the shoulder diameter to the probe length is 2:1 or less.

Fig.1a.

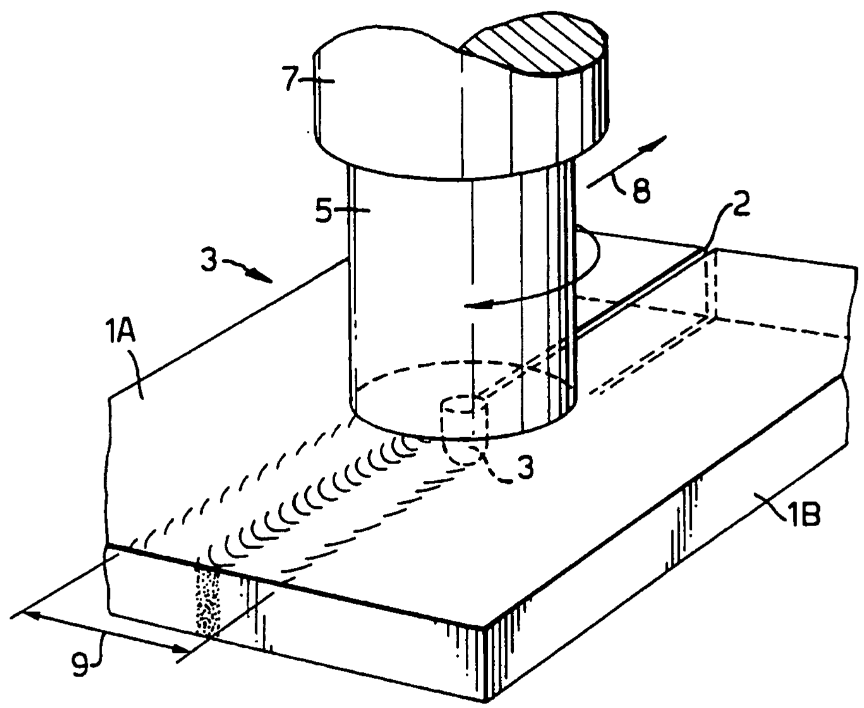


Fig.1b.

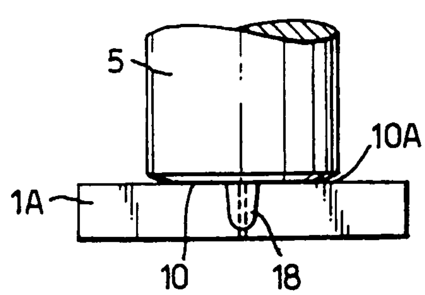
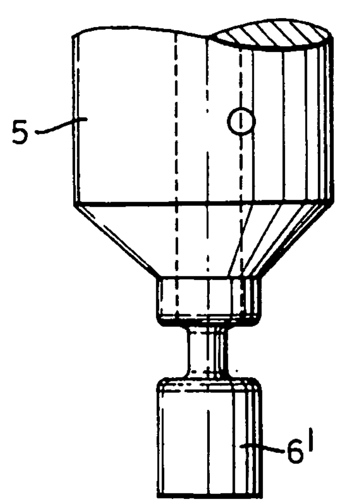


Fig.1c.



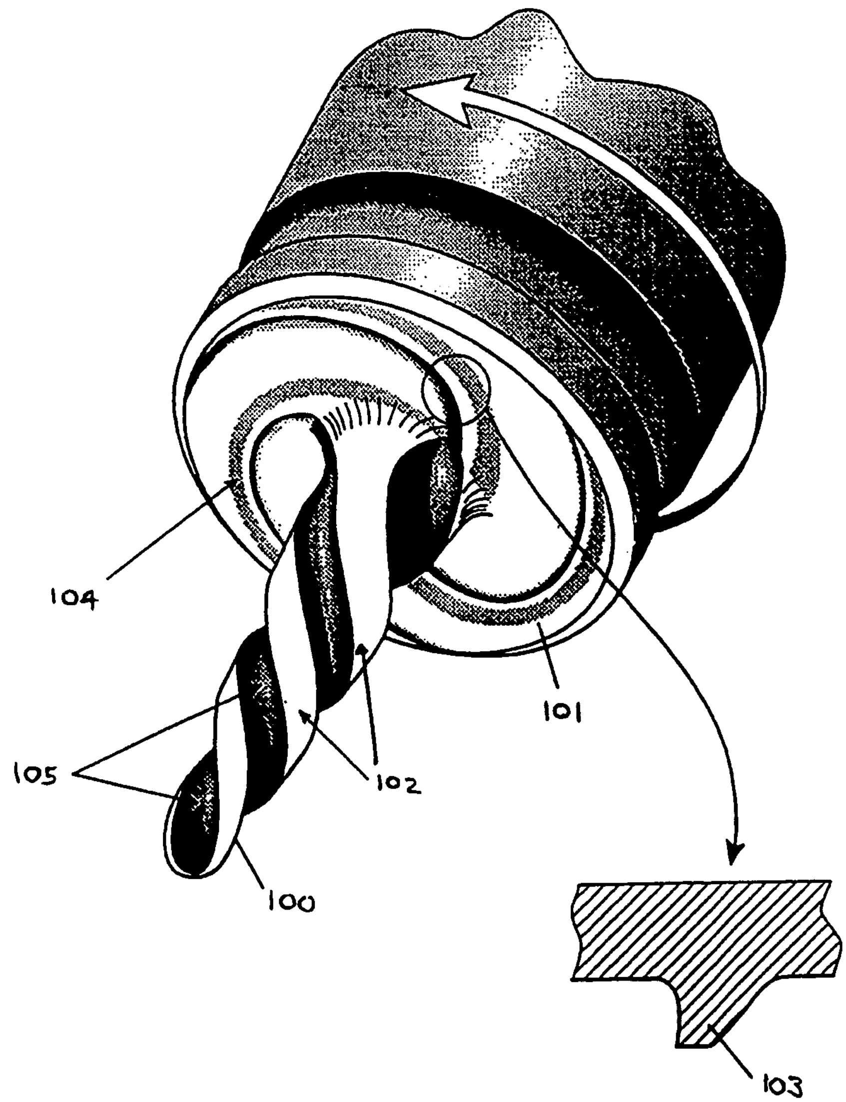


FIG. 2

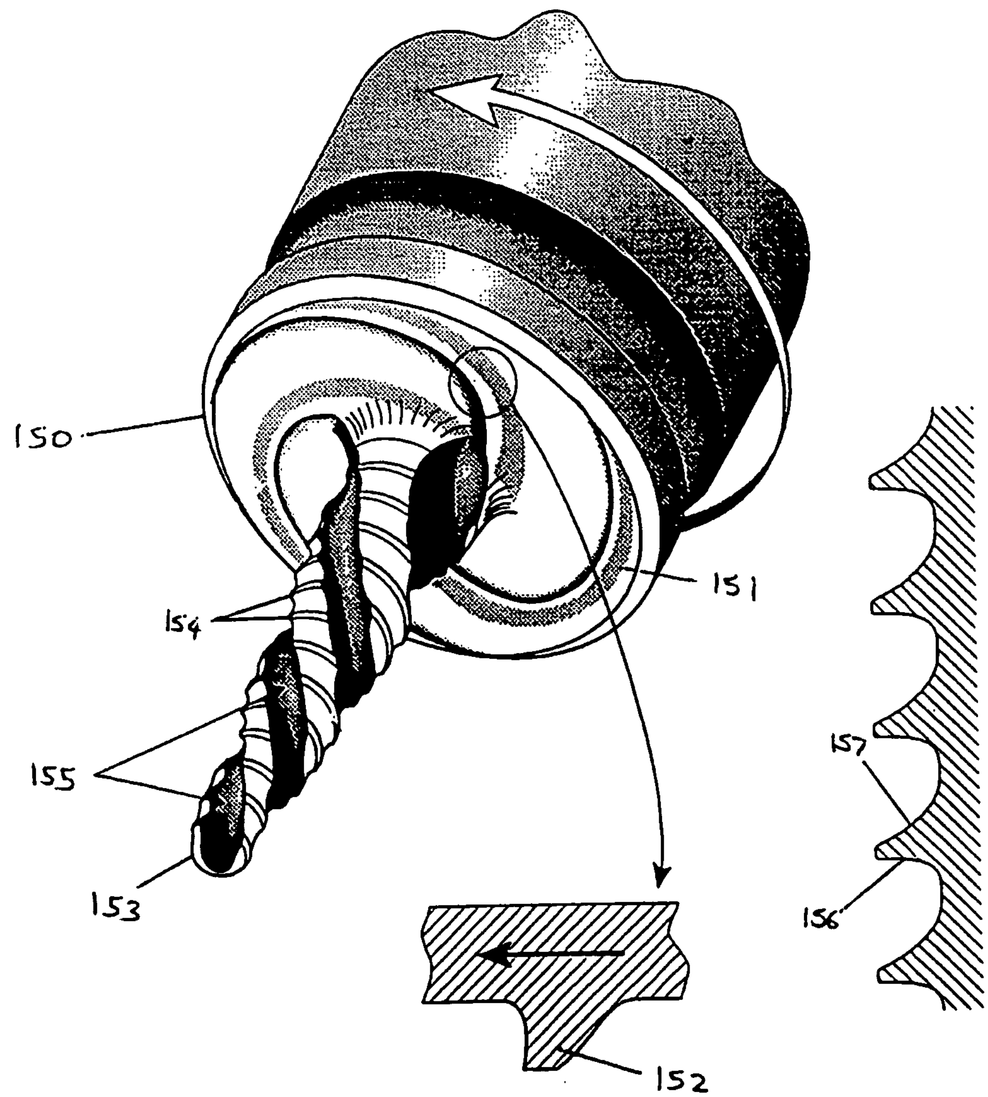


FIG. 3A

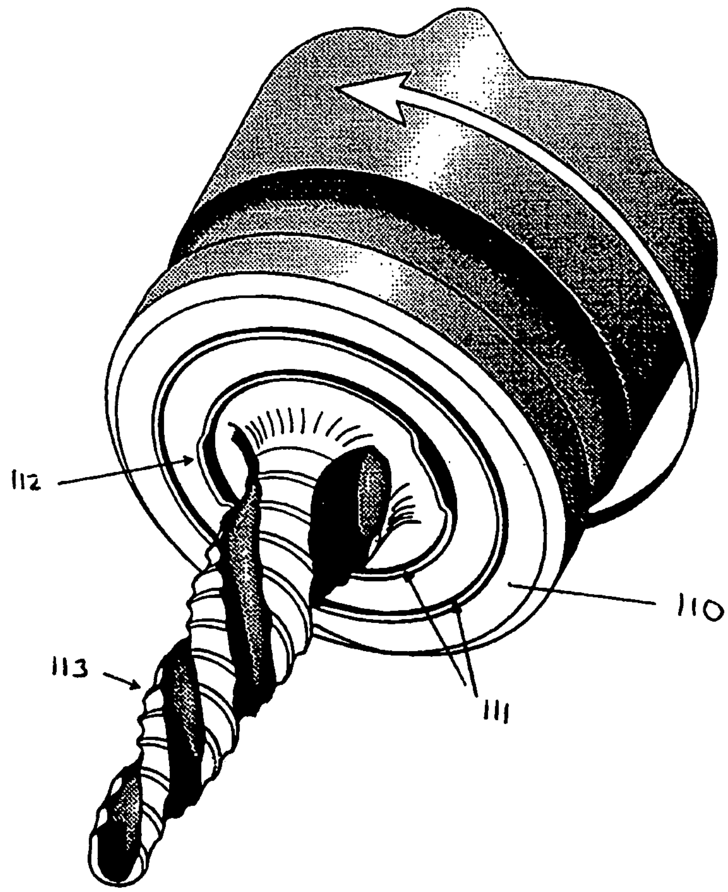


FIG. 3B

Fig.3c.

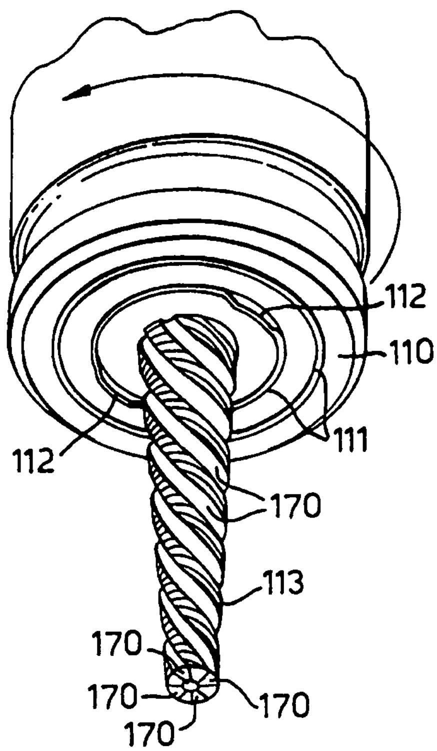


Fig.4.

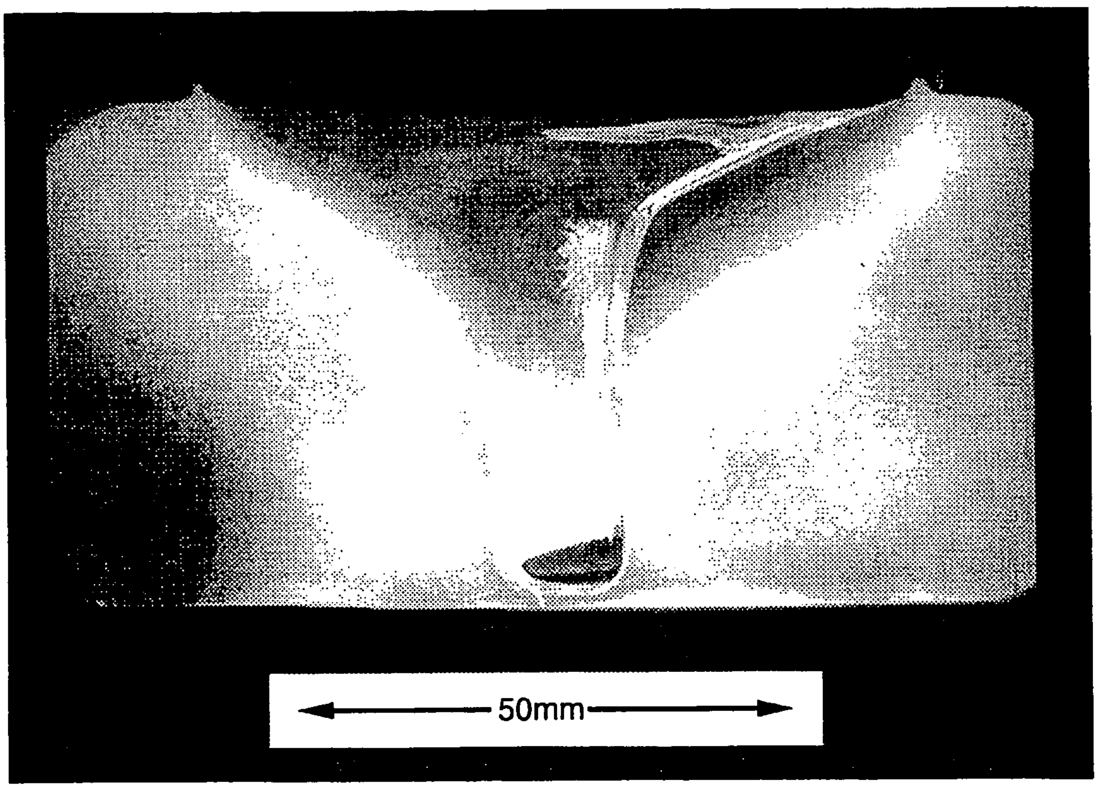
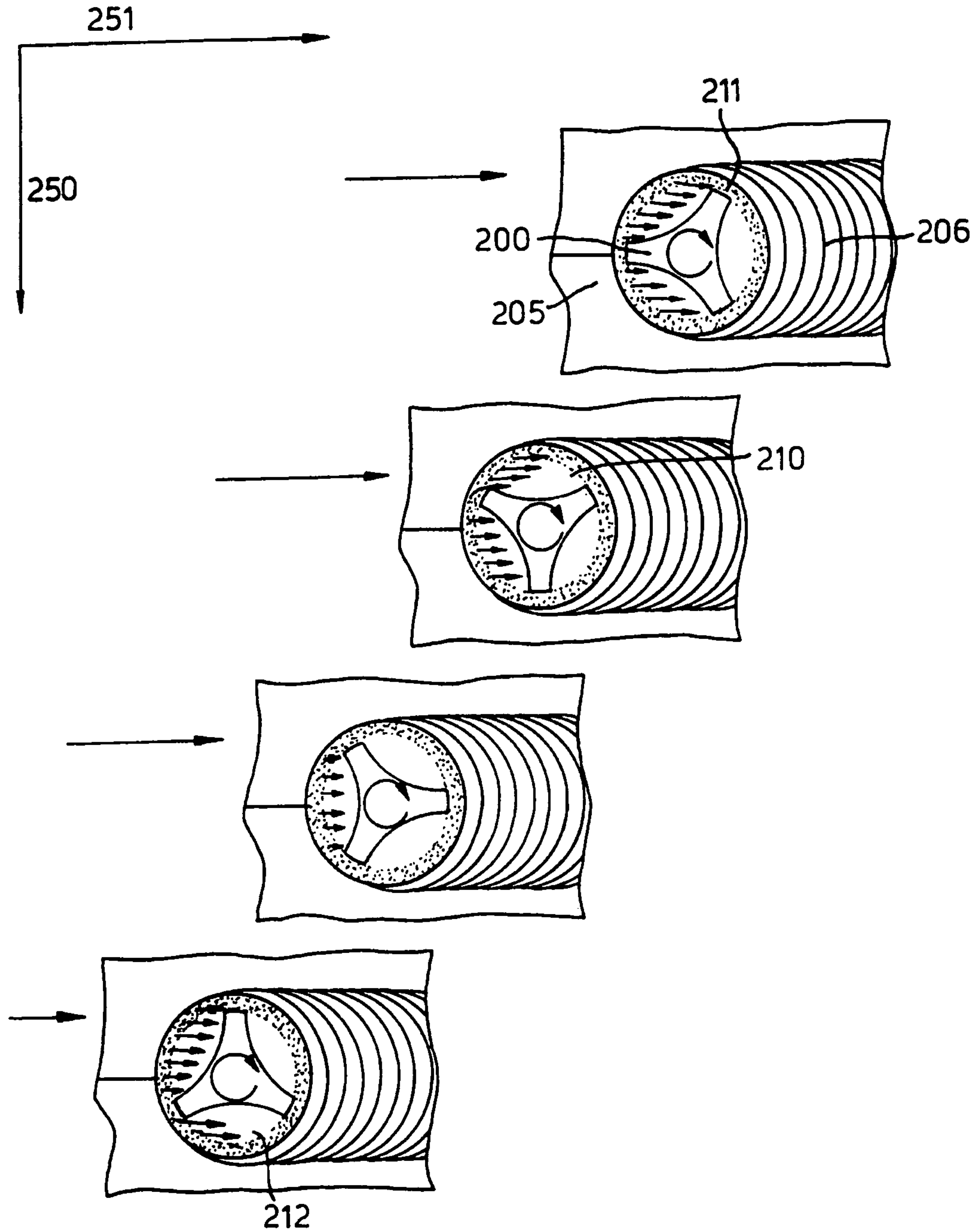


Fig.5.



INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B23K20/12

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B. FIELDS SEARCHED

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	see page 15, line 32 - page 16, line 5; figure 15	5
Y	GB 2 306 366 A (WELDING INST) 7 May 1997 cited in the application see page 10, line 27 - line 34; figures 6E,3C	5
A	US 5 718 366 A (COLLIGAN KEVIN JAMES) 17 February 1998 see column 7, line 1 - line 10; figure 2A	1

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[X] Further documents are listed in the continuation of box C.

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

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